New Particles and Forces BNL Summary

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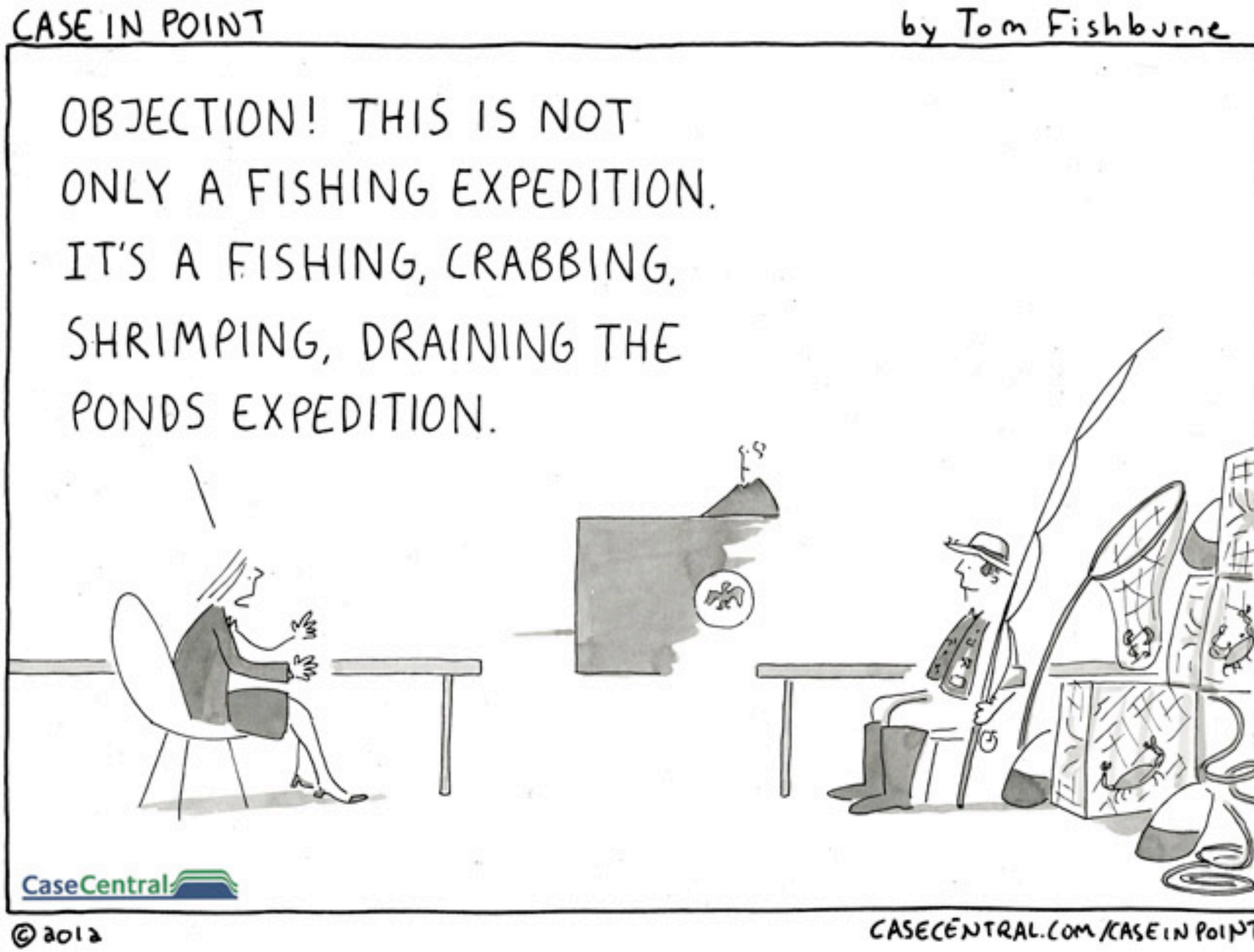
Thanks to all participants

Especially for people who came across the oceans on the short notice, gave excellent talks, and made this meeting intellectually stimulating

Guiding Principles

Guiding Principles

- Whatever Frontier you're in, you're exploring the unexplored



Guiding Principles

- Naturalness
- Higgs as a portal into exotics
- Dark Matter
- Flavor

- make connections between different experimental approaches and frontiers

Naturalness

- Has been our guiding light (prejudice?) for the last couple of decades

Naturalness

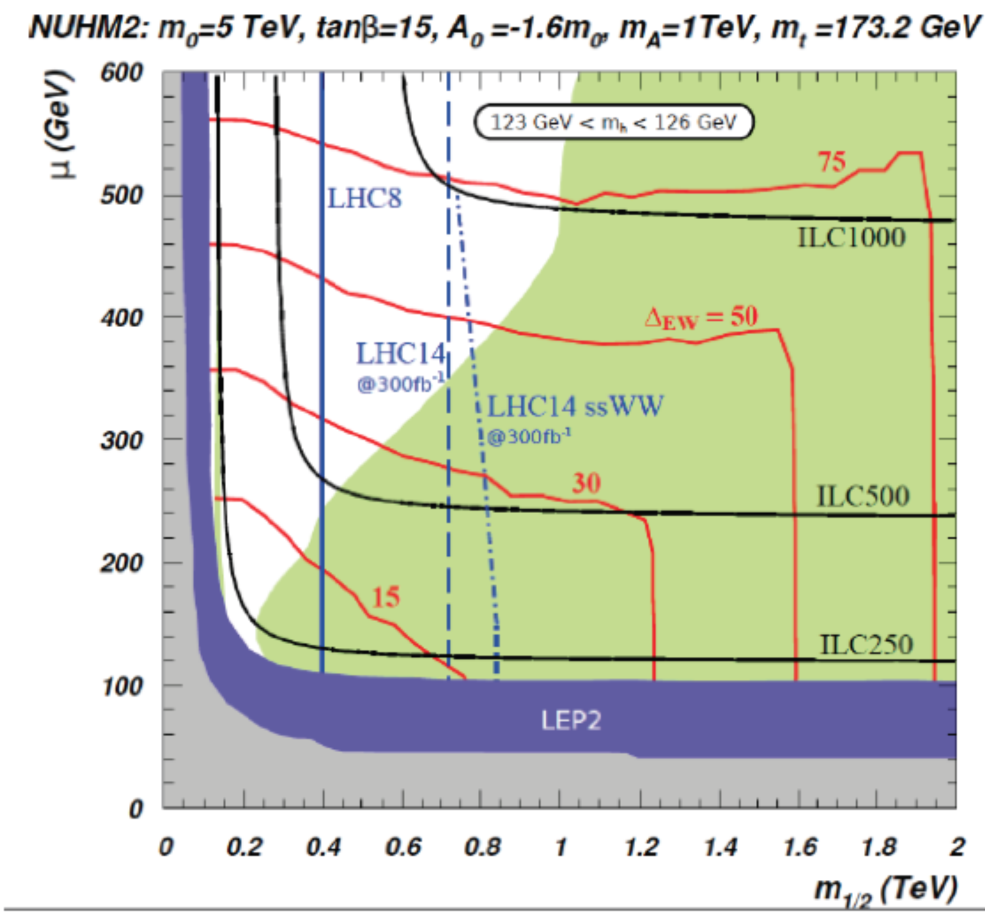
- Has been our guiding light (prejudice?) for the last couple of decades
- While 8 TeV searches killed a lot of natural SUSY models, for each one killed there are at least two other natural models, as improbable as the one we killed, just harder to find
  - Squeezed, RPV, complex cascades, etc, etc

Natural SUSY at the LHC:

Naturalness

Baer

LHC/ILC complementarity



While LHC has some capacity, it will require ILC to draw the story of SUSY electroweak naturalness to a conclusion!

A. Mustafayev plot

Challenge to HL-LHC: can one design a more sensitive analysis?

Benchmark Models

MODELS UNDER STUDY

- Results of brainstorming session on new physics scenarios at UC Irvine meeting here

Models are classified under two broad categories:

- Simplified models, where only the minimal particle content is specified, which are valuable for characterizing the discovery potential of particular classes of signatures
- Complete models, where the full model is specified, which are valuable for connecting the power of different classes of experiment, especially across the Energy, Cosmic and Intensity frontiers

Complete models

SUSY complete models: pMSSM

- Contact people: Tom Rizzo, Joanne Hewett
- Details of benchmark models: here
- Status: generating signal events for LHC14

Post-LHC8 Benchmark Points from High Scale Models and pMSSM

- Contact people: Howie Baer, Jenny List
- Details: Webpage with SLHA files and spectrum plots, article

RS complete models:

- Contact: Kaustubh Agashe
- Talk on benchmark models: here & here
- Details of benchmarks (including LHE files): here
- Status: generating signal events for LHC14
-
- RS models with flavor implications: Kaustubh Agashe, Martin Bauer, LianTao Wang
- Status: Defining benchmarks (preliminary version is here)

Simplified models

SUSY

- Contact people: Tim Cohen, Kiel Howe, Jay Wacker
- Talk on benchmark models: here
- Proposed benchmark models to simulate: here
- Details of weighting procedure using Madgraph: here

@ the Wiki: snowmass2013.org

After considerable debate, there is a model set that highlights strengths of all facilities

Now we need to make sure that there at least a few complete models that are considered for all facilities and across frontiers

RPV

Evans

Motivated Benchmark Models

by Naturalness, 3rd Generation Dominance and Variety of Final States

Coupling	Production	Final States	Search	Nat.	3G
$LLE122$	$\tilde{g}/\tilde{u} \to \tilde{B}$	$jj + \ell^+\ell^-\mu^+\mu^- + \not{E}_T$	$M\ell$	✗	✗
	$\tilde{W}$	$\ell^+\ell^-\mu^+\mu^- + \not{E}_T$	$M\ell$	✗	✗
$LLE233$	$\tilde{t} \to \tilde{H}$	$b\bar{b}\tau^+\tau^-\ell^+\ell^- + \not{E}_T$	$M\ell$	✓	✓
	$\tilde{H}$	$\tau^+\tau^-\ell^+\ell^- + \not{E}_T$	$M\ell$	✓	✓
$LQD221$	$\tilde{g}$	$\{\ell^\pm jj\}\{\ell^\pm jj\}$	$SS\ell$	✗	✗
$LQD321$	$\tilde{t} \to \tilde{H}$	$\{b\{\tau^+ jj\}\}\{\bar{b}\{\tau^- jj\}\}$	$OS\tau$	✓	✓
$LQD232$	$\tilde{g} \to \tilde{t}$	$t\bar{t}\{\mu^+ j\}\{\mu^- j\}$	$M\ell$	✗	✗
$LQD333$	$\tilde{t}$	$\{\tau^+ b\}\{\tau^- b\}$	LQ	✓	✓
$UDD212$	$\tilde{g}$	$\{jjj\}\{jjj\}$	Trijet	✗	✗
	$\tilde{t} \to \tilde{B}$	$t\bar{t}\{jjj\}\{jjj\}$	$\ell + n$ jets	✓	✗
$UDD312$	$\tilde{t}$	$\{jj\}\{jj\}$	Dijet Pairs	✓	✗
$UDD323$	$\tilde{t} \to \tilde{H}$	$bb\{bbj\}\{bbj\}$	b-jets	✓	✓
$LH3$	$\tilde{H}$	$W^+W^-\tau^+\tau^-$	$M\ell$	✓	✓

Nat. – A “natural” topology, i.e. stops and higgsinos

3G – RPV coupling compatible with a 3rd generation dominant ansatz

- All scans chosen to be linear in mass – others in ratio

UED

Kong, Wang

HF4: UED Benchmarks

- We propose the following:
  - Consider 5D UED only
    - 6D model needs to address an issue with DM (too low KK scale)
  - Minimal UED
    - two parameters: R and Λ (cutoff)
    - cutoff dependence: log($R\Lambda$)
    - mass spectrum from radiative correction (no boundary terms)
    - Include Δ_{q1}, explore the connection with direct detection.
  - NMUED with brane terms for strong sector
    - two additional parameters: bulk mass term μ, boundary parameter *r*.
    - New signals: 2nd resonance $\Rightarrow$ SM quarks, ...
  - Signatures (standard SUSY search + resonances)
    - level 1: jets + n-leptons + met, n=0,1,2,3,4
    - level 2: dijet, dilepton and lepton-neutrino final states

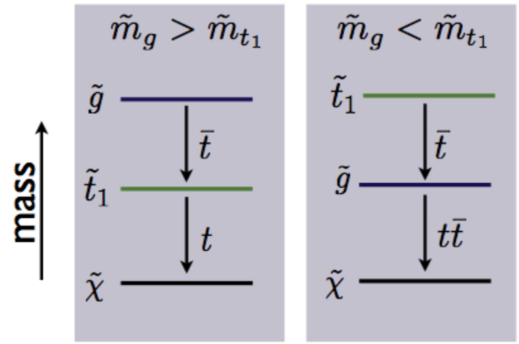
Simplified models

gluino + stop + LSP simplified model

Production:

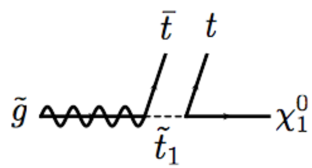
$$pp \to \tilde{g}\tilde{g},\ \tilde{t}_1\tilde{t}_1^*$$

Decays:



$$(2-6)t + \text{MET}$$

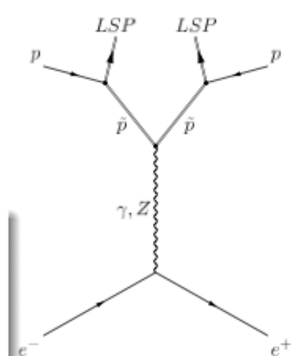
Howe
Berggren



Simplified SUSY models at ILC

- All is known for given masses, due to SUSY-principle: "sparticles couples as particles".
- This doesn't depend on the SUSY breaking mechanism !
- Obviously: There is one NLSP.

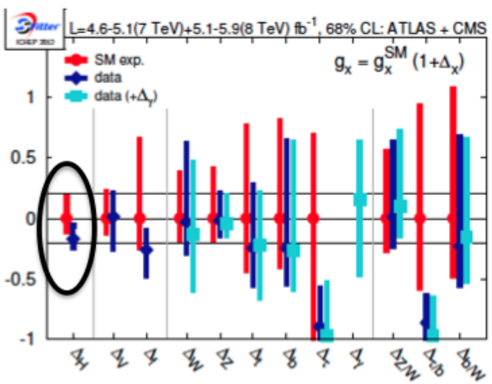
- Model independent exclusion/ discovery reach in $M_{NLSP} - M_{LSP}$ plane.
- Repeat for all NLSP:s.
- Cover entire parameter-space in a hand-full of plots
- Cf. LEP !

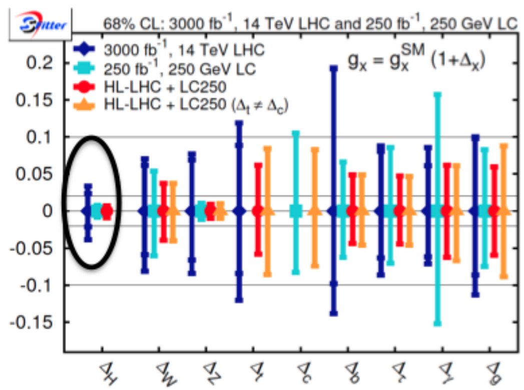


Higgs as A Portal to Exotica

Dawson

Higgs Singlet: Present and Future





[Klute, Lafaye, Plehn, Rauch, Zerwas]

6

- It takes only a tiny coupling to produce a perceptible effect in Higgs branching fractions
- Measuring couplings to 1% is equivalent to being able to make discovery if the deviation from the SM is 5%

Rare Higgs decays

Essig

How many exotic decays to expect?

assume BR(h→aa) = 10%, LHC8, 20/fb

channel	# events (raw)
ggF	39000
VBF	3150
W($\ell\nu$)+h	280
Z($\ell\ell$)+h	55
ttH	260

Associated Production (AP)

Can always trigger w/ AP… but not many events

Depending on `*a*` decays, ggF/VBF may be better

- If make fairly reasonable assumptions
  - Get ~all h+V(leptonic)
  - Get ~10% of VBF
- Have 6500 higgses without any trigger bias @LHC8
- Some decay modes have very small backgrounds – light resonances, long-lived particles, MET, etc

Dark Matter

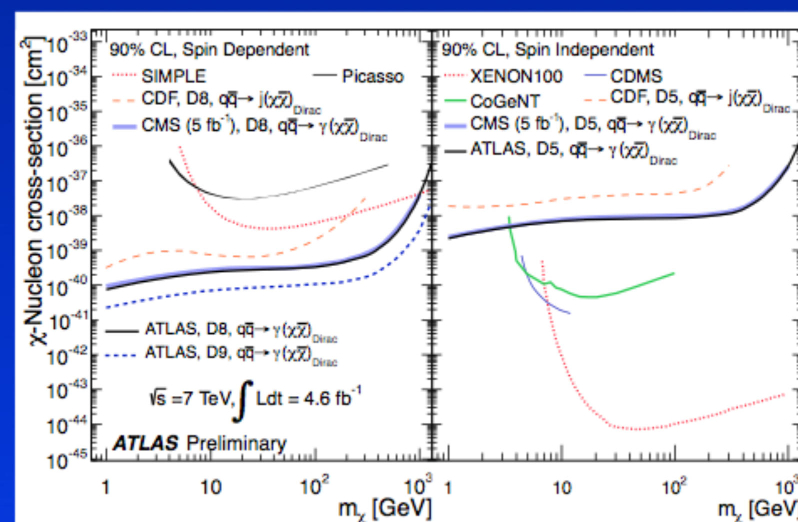
Dark Matter Operators

Look for SM SM to XX + (jet+photon)

Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

- Birkedal, Matchev, Perelstein (2004), Feng, Su, Takayama (2005), J. Goodman et al., Phys. Rev. D82, Harnik, Kopp, Tsai 1103.0240; Bai, Fox, Harnik (Tevatron) JHEP 1012 (2010) 048; Cheung, et al. 1

Pierce



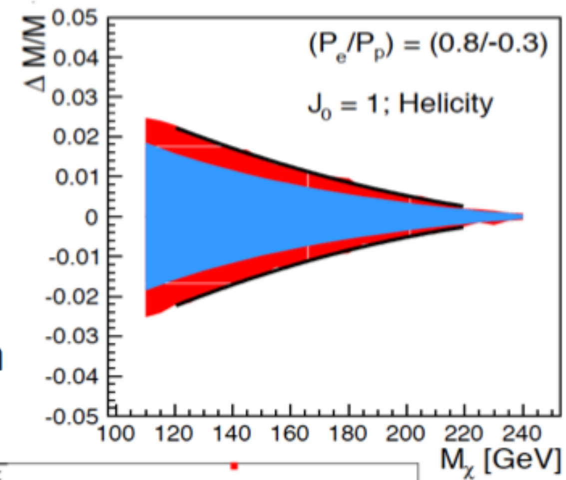
Dark Matter

- Can precisely measure mass and spin at ILC

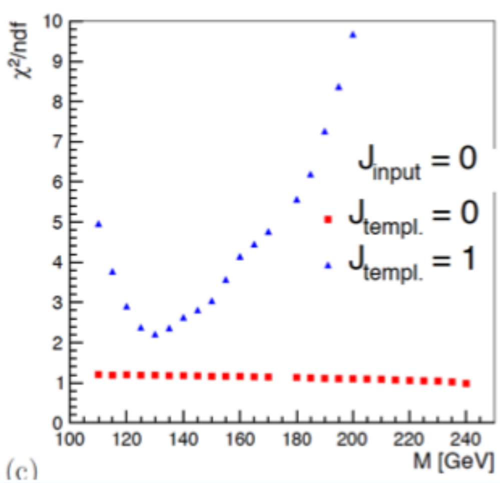
List

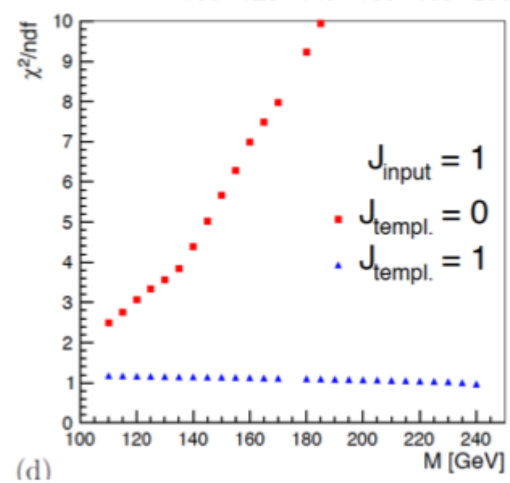
WIMP characterisation

- Mass resolution
  eg ILC @ 500 GeV, 500fb^{-1},
  P(e^+,e^-) = (-30%,80%)
  - 1-2% level
    - Dominated by conservative assumption on knowledge of beam energy spectrum



- Dominant partial wave deter-mination: correct hypothesis clearly favoured

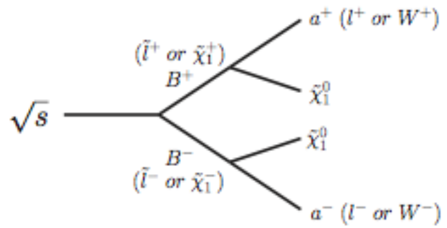


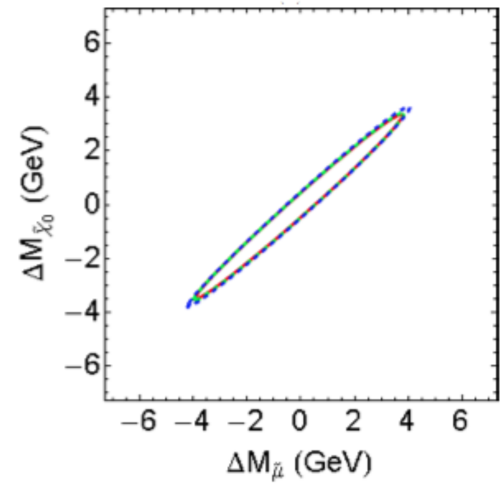


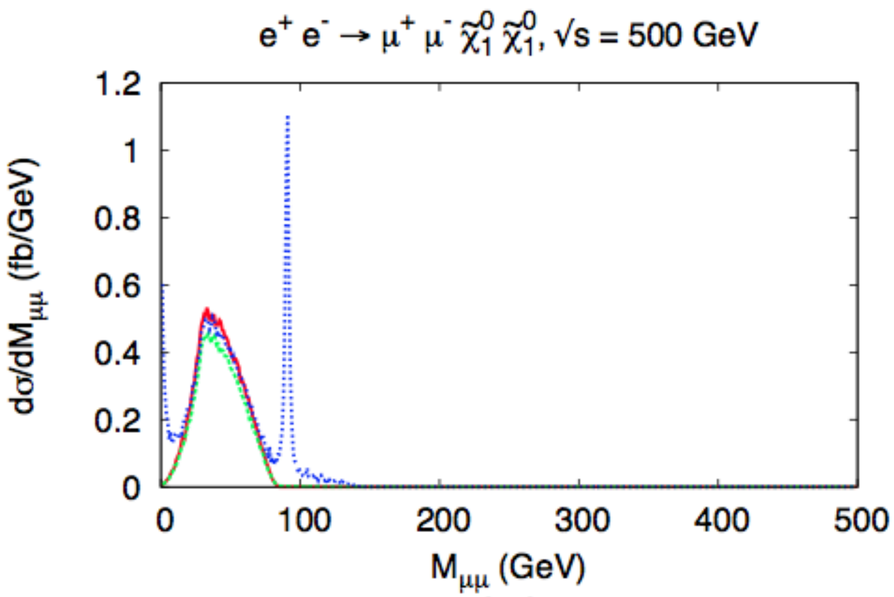
Dark Matter

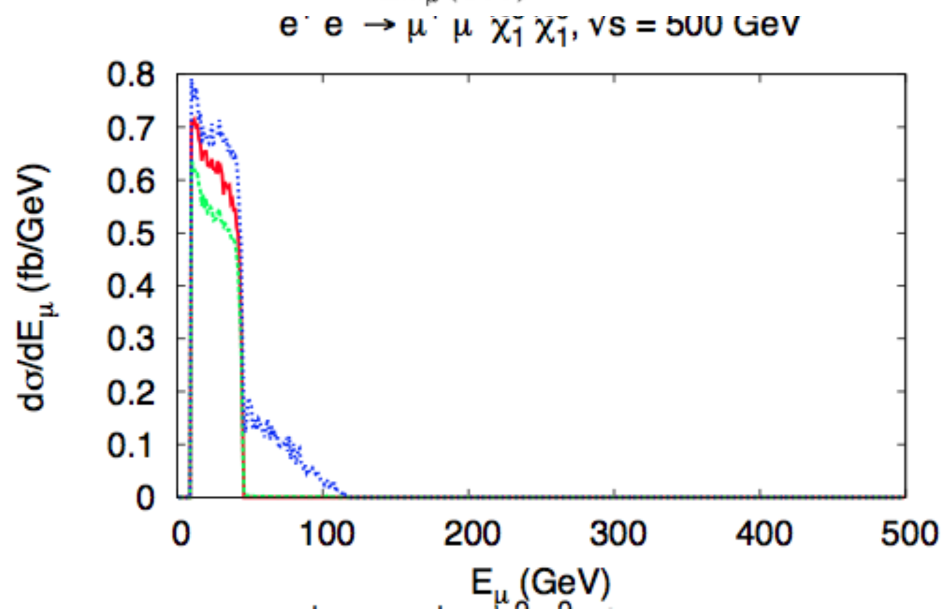
- Can precisely measure mass and spin at ILC

Christensen









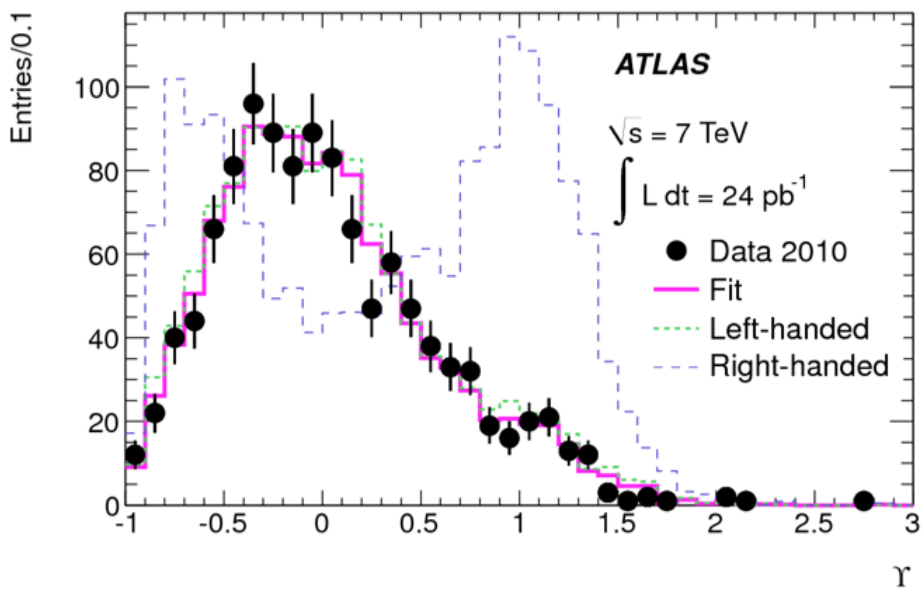
Tool for HL-LHC?

Demers

the Power of Statistics

Measurements that rely on tau polarization CAN be done at hadron colliders

Process	P_τ Prediction
$W^\pm \to \tau\nu$	-1
$H^\pm \to \tau\nu$	+1
$Z \to \tau\tau$	≈ -0.15
$H \to \tau\tau$	0

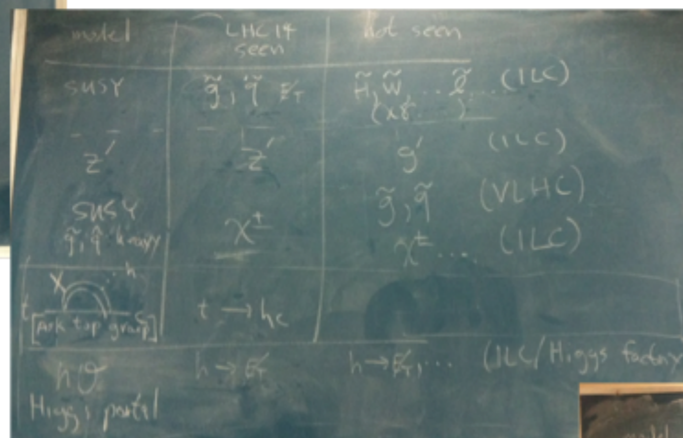


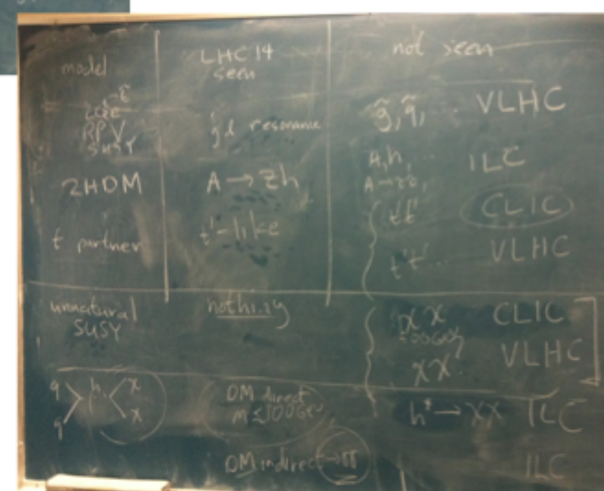
$$P_\tau = -1.06 \pm 0.04\,(stat)\,^{+0.05}_{-0.07}\,(syst)$$

No neat tables

- Two challenges: we are looking for too many things, and we're asked to come up with a 20 year vision when our understanding will likely undergo fundamental change in just 2-3 years as the 14 TeV LHC are in
- Have to make hypotheses about what is found and not found at the LHC
  - Basically have to tell ourselves stories about different possibilities

Story boards

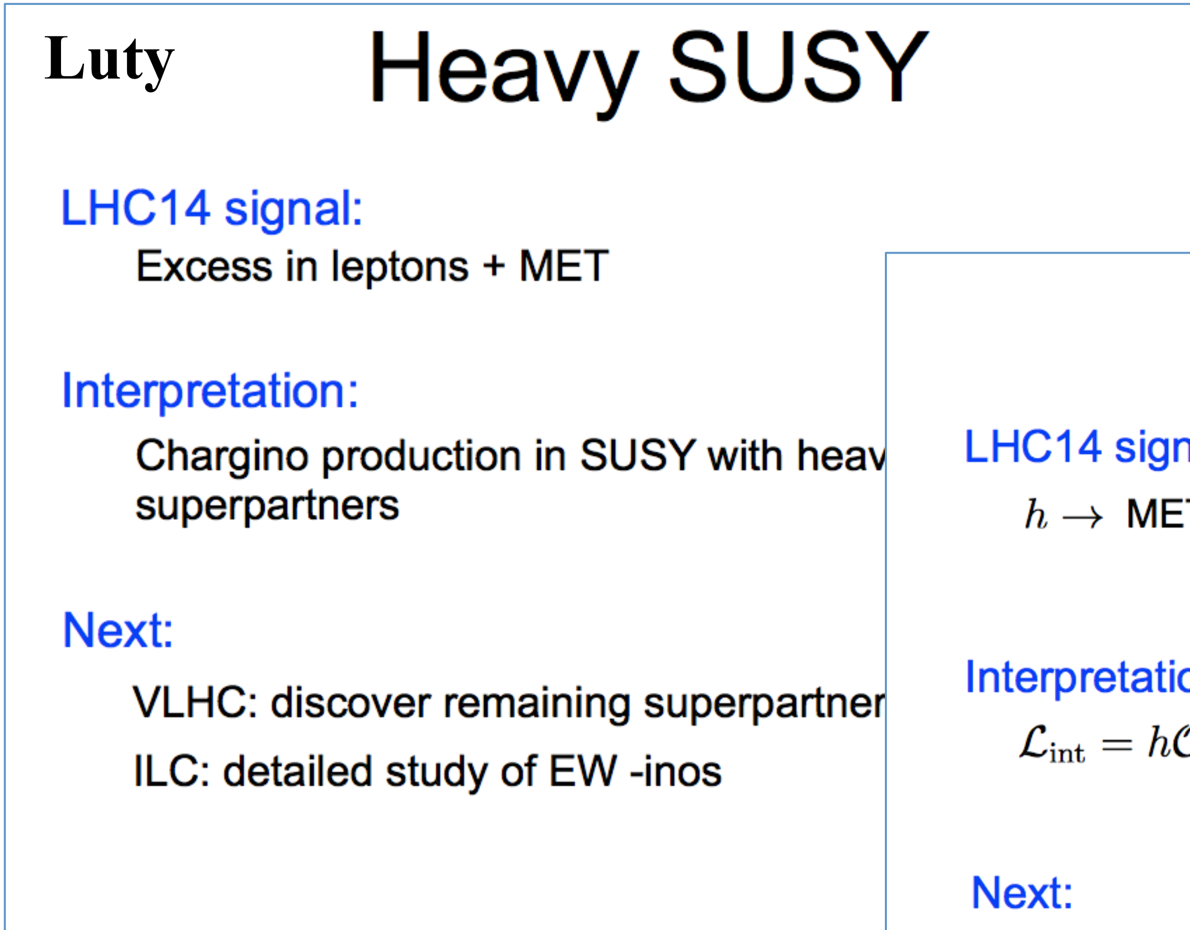


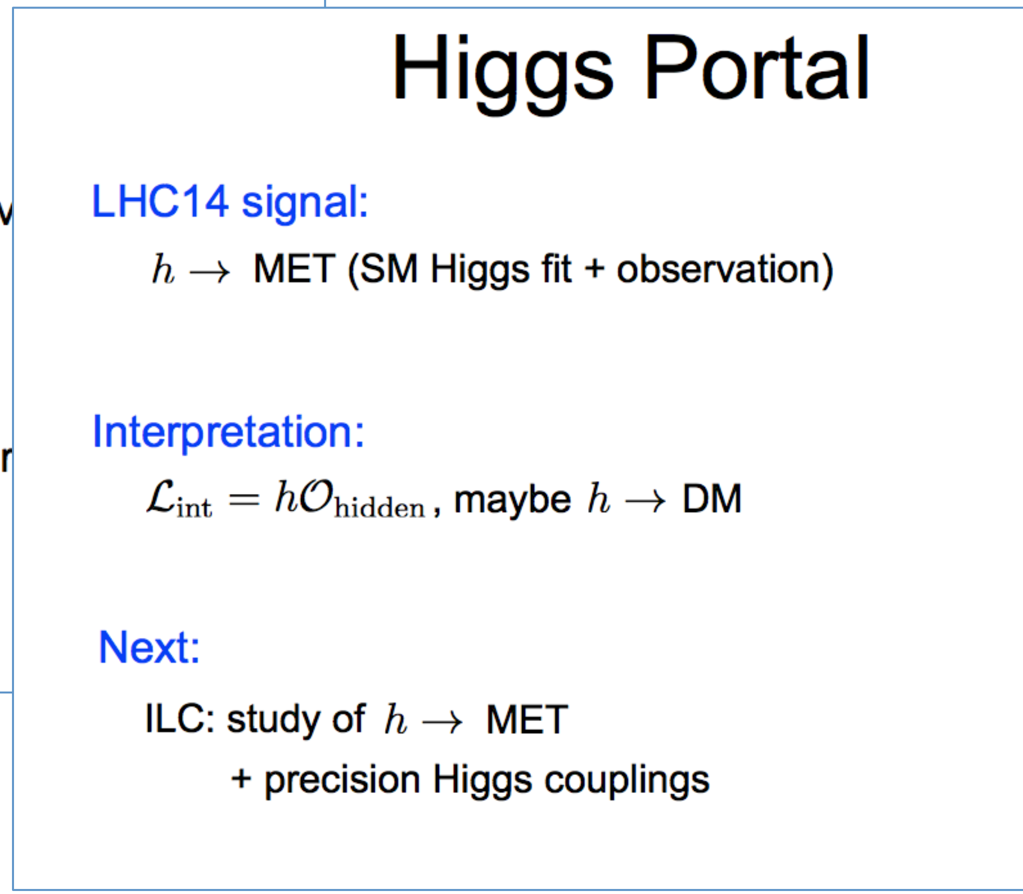


Blackboards from brainstorming session at the Irvine meeting

Luty

Story board examples





Story board examples

Luty

Heavy SUSY

LHC14 signal:

Excess in leptons + MET

Interpretation:

Chargino …

Ne…

…discover remaining superpartner…

ILC: detailed study of EW -inos

$h \to$ MET (SM Higgs fit + observation)

Interpretation:

$\mathcal{L}_{\rm int} = h\mathcal{O}_{\rm hidden}$, maybe $h \to$ DM

Next:

ILC: study of $h \to$ MET

+ precision Higgs couplings

The benchmark model studies will infuse these stories with quantitative substance

Common tools

Simulation framework for Snowmass

Delphes-3 fast simulation (https://cp3.irmp.ucl.ac.be/projects/delphes)

- Delphes3 supports addition of PU events
- Many improvements were motivated based on current studies

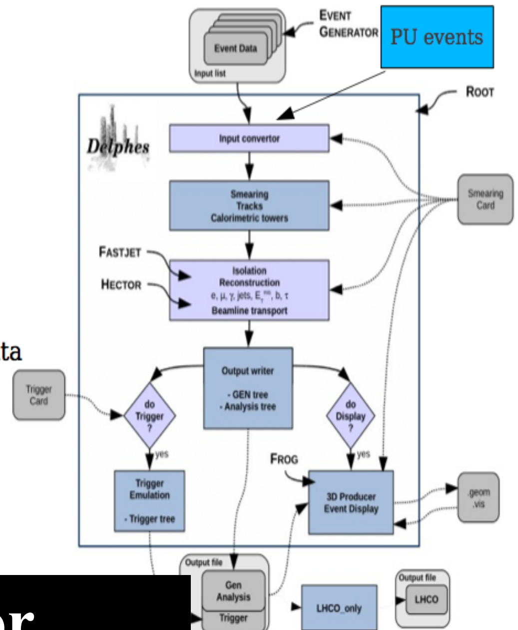
For Phase-I studies:

We plan to use Delphes3 framework with:

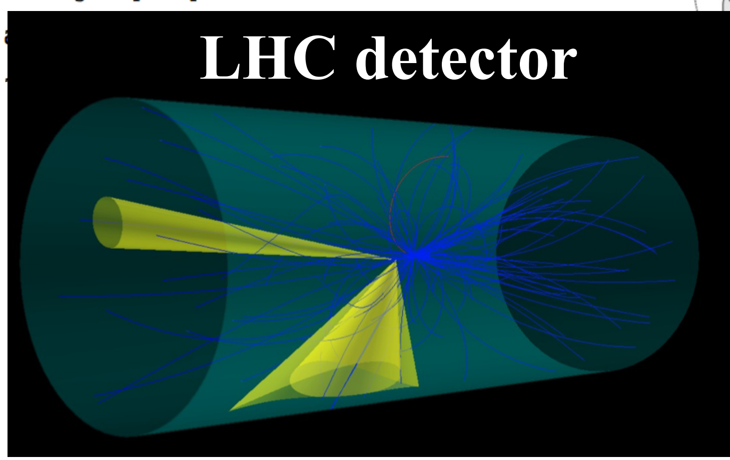
- realistic detector performance with PU =50
- parameterize using available full simulation
- retain object performance as obtained using data
- use best of both ATLAS/CMS performance (if publicly available)

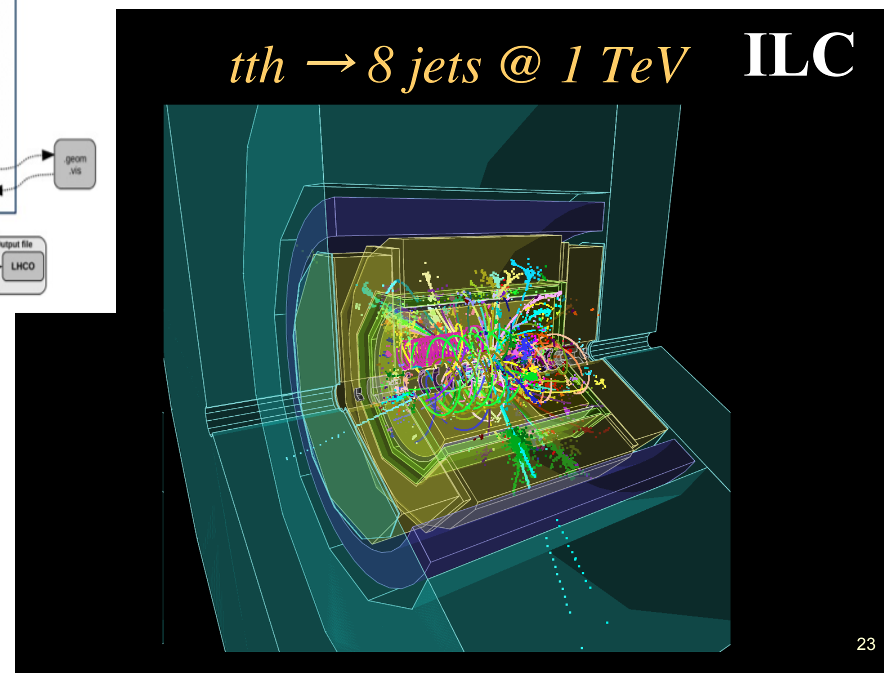
For Phase-II studies:

- use higher pileups – 140
-



Padhi
Graf





Common Tools

- Generation of compressed spectrum signals

Howe

Weighted event generation

Goal: Generate events in appropriate bins of jet recoil momentum (in practice, HTJ)

Procedure: (see http://www.stanford.edu/~timcohen/WeightedEventsUsingMadgraph.pdf)

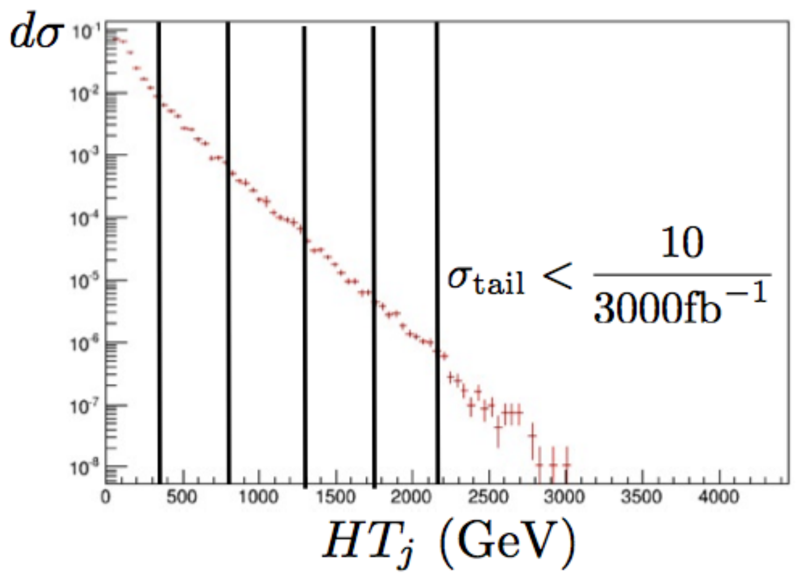
1) Differential Cross Section from MadGraph Survey (steps of 100 GeV)

2) divide into bins

$$\frac{\sigma_n}{\sigma_{>n}} = x = 0.9$$

3) generation (MG5 + pythia), N=10000 in each bin

4) Reconstruction and combine with weights



Kiel Howe, Stanford, Brookhaven Snowmass Energy Frontier Workshop '13

Summary

- We have established the benchmarks
  - Need your help to study them, especially
    - Carry the complete models across facilities
    - Study simplified models to probe difficult regions (i.e. squeezed)
  - Make the "stories" convincing for ourselves
- The time is very short – we're supposed to have draft of "conclusions" by June 15
- This is a community exercise! We need you – and your friends and colleagues
  - Help us define the stories
  - Make studies that make them credible
- snowmass-bsm@slac.stanford.edu
- http://snowmas2013.org